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NAVSTAR GPS APPLICATIONS TO TEST AND TRAINING

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ABSTRACT

This paper summarizes a ~~fifteen-month~~ study on the uses of the NAVSTAR Global Positioning System (GPS) at the National Ranges operated by the United States Army, Navy, and Air Force for weapon system development, test, and training. It was conducted by a special triservice committee chartered by the Office of the Undersecretary of Defense for Research and Engineering. The primary objectives were to evaluate GPS application areas, identify and analyze technical issues, and recommend cost- and mission-effective applications.

The study found that GPS technology will have a wide variety of use at the ranges with significant cost advantages and that the technical issues, some of which are quite challenging, do not pose serious obstacles to widespread employment. It will be necessary to design and develop a new family of GPS receiver hardware for range uses since the current generation of receivers does not satisfy the accuracy, data rate and continuity, and size demands of the typical range environment. The study provided the family definitions for GPS range equipment and the basis for a joint-service development program under Air Force direction at Eglin AFB, Florida.

INTRODUCTION

The NAVSTAR Global Positioning System (GPS) is a three-dimensional navigation system that will employ eighteen satellites in circular 20,200 kilometer (12 hour period) orbits (Figure 1). By listening to four or more satellites, users of GPS can derive position, velocity, and time with high precision and uniform accuracy on a global basis(1). NAVSTAR GPS is being developed by a triservice Joint Program Office located at the Air Force's Space Division Headquarters in Los Angeles, California. The six satellites presently in orbit provide a few hours each day for equipment development and testing. The operational satellites will be placed in orbit beginning in 1986 and full 24-hour capability will be achieved by late 1988 or early 1989.

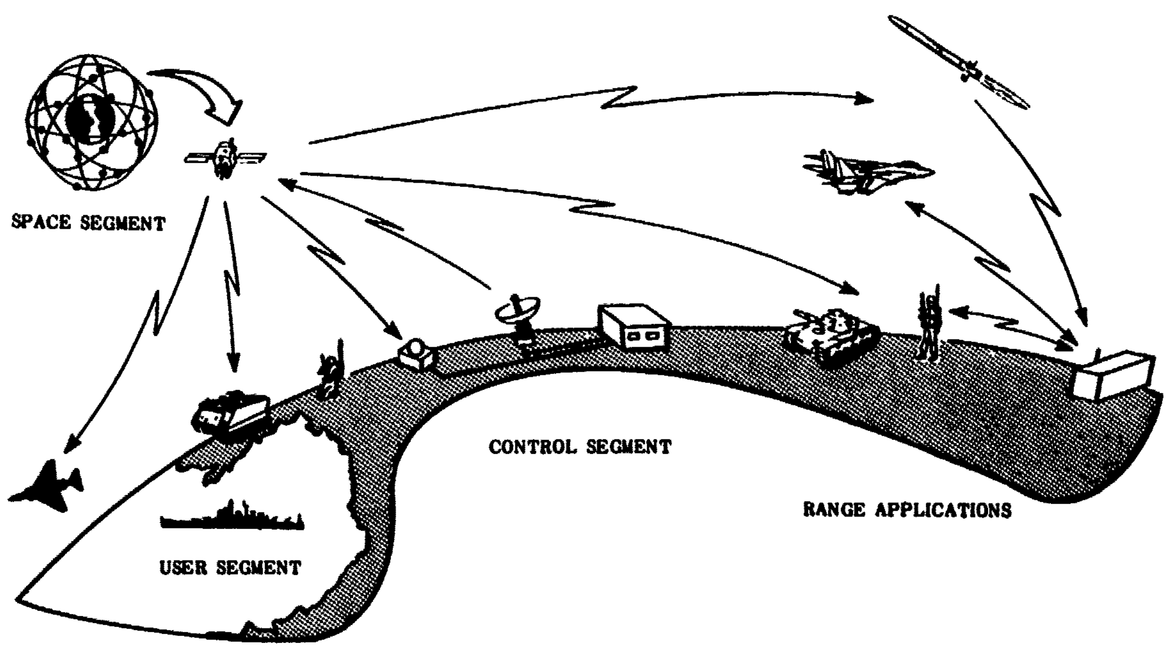

FIGURE 1 NAVSTAR GPS OVERVIEW

The advent of GPS offers a major opportunity for fielding a standardized, cost competitive Time-Space-Position Information (TSPI) system on the national ranges. A GPS-based TSPI system would provide precise and uniform tracking accuracy to unlimited numbers of test articles between the surface and low earth orbit. The individual ranges would have to invest in telemetry data link upgrades and data handling systems, but might be able to avoid the high capital investments of other types of TSPI equipment (phased-array radars, time-multiplexing systems, etc.) in future expansion and improvement programs. On the other hand, there are several significant performance and implementation issues that need to be resolved before the potential benefits of GPS as a test range asset can be realized.

The Department of Defense (OUSDRE/DDT&E) issued a memorandum to the three services in May, 1981 requesting that the Air Force lead a triservice study of GPS applications to test and evaluation ranges and the training ranges. The objectives were:

- Evaluate generic test and evaluation and training requirements for GPS application.

- Identify and analyze the technical problems associated with GPS applications.

- Recommend interim and long-term applications of GPS.

The third objective was expanded during the course of the study to include identification of a lead organization and development of a management approach to a long-term equipment acquisition program.

The study committee was organized in September, 1981 with two members each from the Army, Navy and Air Force range organizations. A final report was delivered in January, 1983(2). The triservice study group has continued to function as an advisory committee to the organization selected as the developer of range equipment: the Instrumentation Directorate of the Air Force Armament Division (AD/YI) at Eglin AFB, Florida(3).

CONCEPTUAL TSPI EQUIPMENT

TSPI data can be obtained by using onboard GPS receivers or frequency translators. A receiver processes the satellite signals and outputs either raw or corrected TSPI data which can be recorded or transmitted to the ground through a telemetry data link. A translator receives the GPS signals and retransmits them on a different frequency for detection and processing on the ground. Translators use up telemetry bandwidth rapidly because at least two megahertz is needed for each simultaneously operating translator. A receiver system uses less than 100 kilohertz of bandwidth, thus permitting large numbers of users to be active at the same time.

Receivers are good candidates for aircraft and test articles with high recovery rates so that the GPS equipment can be reused. Being simpler, smaller, and less expensive than receivers, translators are well-suited for small test articles that are expendable or likely to exhibit a high attrition rate such as missiles and drones. In general, the type of onboard equipment chosen for a particular application will be dictated by performance requirements, form-fit factors, and costs relative to the test article itself.

A range system concept employing a digital translator is shown in Figure 2. The carrier for the retransmitted signal is derived from the translator local oscillator and used at the receiving site to aid signal tracking and correct translator local oscillator error(4). Vehicle position and velocity are then estimated using special processing algorithms(5). Both analog and digital translators have been built and tested, thus verifying the concepts(6,7).

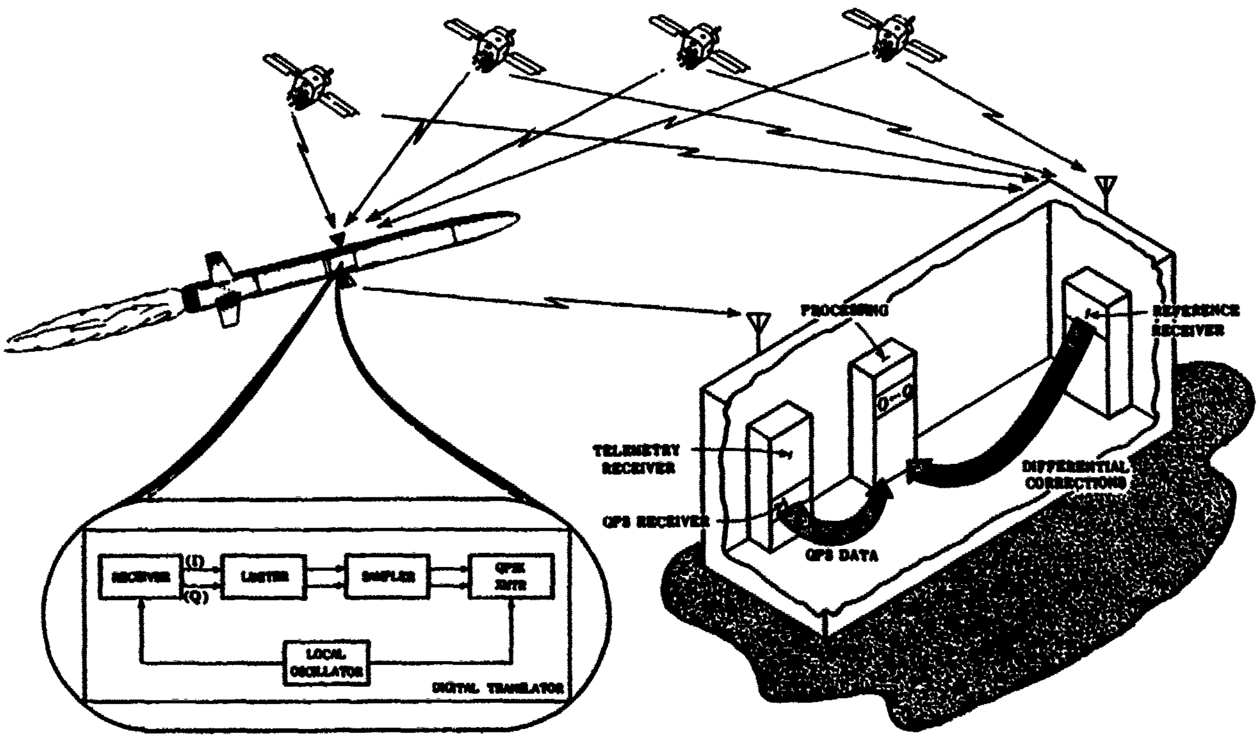

FIGURE 2 TRANSLATOR SYSTEM CONCEPT

In the course of the study, two types of receivers for use on test vehicles were defined(Figure 3): A Low Dynamic Set and a High Dynamic Set. The Low Dynamic unit would be used in applications where output data is required once or twice per second at most and when accelerations are less than 10 meters/sec^2 (infantry, ground vehicles and ships). This Set would operate on the GPS L1 frequency only with two detection channels alternately switched among satellite signals to generate the basic range and range rate data.

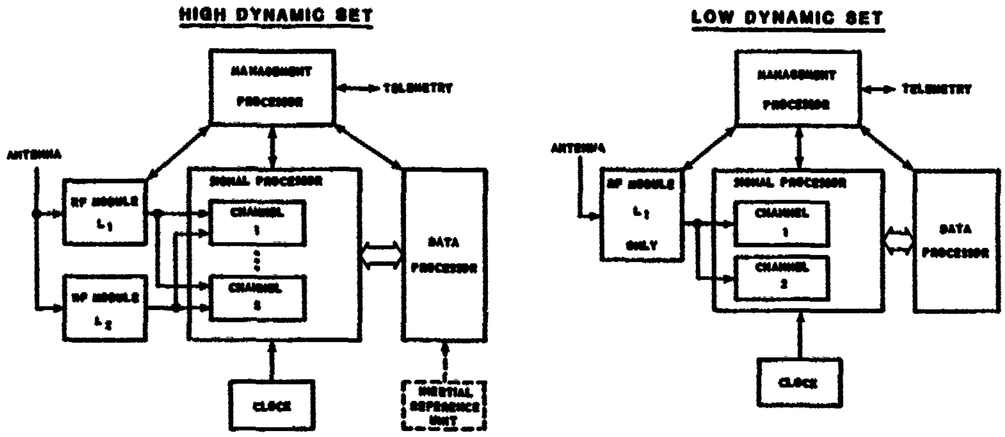

FIGURE 3 INSTRUMENTATION CONCEPTS

The High Dynamic Set would be suitable for vehicles with accelerations up to a maximum of 100 meters/sec^2 (aircraft, helicopters and drones). This unit would operate on both L1 and L2 frequencies, simultaneously track at least four satellite signals and produce new TSPI estimates at rates up to twenty per second corrected for ionospheric delays. In addition to producing absolute TSPI estimates, the High and Low Dynamic Sets could also operate in the differential mode described in the next section.

PERFORMANCE ISSUES

The principal categories of concern with regard to performance are data quality (rate, accuracy, precision and dynamic lag) and data continuity (time-to-first-fix* and data dropouts). Many of the items in these categories are closely allied with the "implementation issues" discussed in the next section.

The TSPI requirements for a wide variety of scenarios and test articles for more than forty service ranges were compiled and analyzed. Based on this compilation, eight idealized (generic) ranges were defined(Table 1) along with typical data requirements (Table 2). Proposed GPS configurations were analyzed to estimate the capabilities of properly designed equipment in the range environment, and a box is drawn around those items in Table 2 that are either stressing for GPS or GPS cannot satisfy. Overall, GPS is effective in meeting most of the requirements and will offer better performance than conventional (non-GPS) systems in many cases.

		ARMY									NAVY						AIR FORCE						
GENERIC RANGES		WSMR	EMR	YPG	EPG	TCATA	CDEC	OTHER TECOM	KTC	BOARDS	PMTC	PMRF	NATC	NWC	AFWTF	TRAINING RANGES	ESMC	WSMC	TFWC	AFFTC	UTTR	GULF RANGE	TYPE II
TRAINING AND OT&E	AIR	●		●							●	●		●	●				●	●	●	●	
	LAND	●	●	●		●	●		●					●									
	SEA (FIXED)										●	●			●								
	SEA (MOVING)															●							
DT&E AND OT&E	LONG RANGE	●	●			●					●	●		●	●		●	●					
	EXTENDED RANGE	●	●																				
	SHORT RANGE (LAND)	●		●	●	●	●	●	●	●				●					●	●	●	●	●
	SHORT RANGE (WATER)		●								●	●	●		●	●	●	●				●	

TABLE 1 GENERIC RANGE RELATIONSHIPS TO DOD RANGES

*Elapsed time from set initialization to subsequent output of accurate TSPI data.

TEST PERFORMANCE PARAMETERS	TRAINING AND OT&E				DT&E AND OT&E			
	AIR	LAND	SEA (FIXED)	SEA (MOVING)	LONG RANGE	EXTENDED RANGE	SHORT RANGE (LAND)	SHORT RANGE (WATER)
REALTIME ACCURACY - POSITION (M) - VELOCITY (M/SEC)	2 - 60 0.03 - 5	5 - 9 1 - 3	60 30	300 ---	6 - 30 0.2 - 2	2 - 6 2	2 - 30 0.3 - 7	2 - 30 0.3 - 7
DATA RATE (#/SEC)	1 - 20	1 - 10	5	1 - 5	20	20	1 - 100	1 - 20
POST TEST ACCURACY - POSITION (M) - VELOCITY (M/SEC)	0.3 - 60 0.03 - 5	2 - 10 1 - 3	3 0.03 - 2	TBD ---	3 - 6 0.003 - 0.03	10 0.003 - 0.006	0.6 - 5 0.03 - 3	0.6 - 5 0.03 - 3
SCORING (M)	0.3 - 3	0.3 - 2	---	---	15	0.3	0.3 - 2	0.3 - 2
NUMBER OF TEST ARTICLES	1 - 90	2 - 2000	50	60 - 125	3 - 10	1	12 - 20	12 - 20
COVERAGE - ALTITUDE (KM) - DISTANCE (KM)	0.3 - 30 60 X 110	0 - 3 60 X 60	0.03 - 15 140 X 140	0 - 20 650 X 930	90 280 X 9260	0.03 - 9 190 X 1100	0 - 30 90 X 280	0 - 30 230 X 370

STRESSING FOR GPS   GPS CANNOT SATISFY

TABLE 2 TSPI REQUIREMENTS SUMMARY

The GPS error budget is dominated by systematic errors in satellite location and signal transmission delays through the ionosphere. These systemic errors can be readily calibrated using a GPS reference receiver at a surveyed site to compute differential corrections(Figure 4). The corrections can then be used in real-time or recorded for post-flight data improvement. A test program is underway to determine the size of the region around the reference receiver for which the corrections are valid, with preliminary findings that the minimum radius is probably greater than several hundred kilometers.

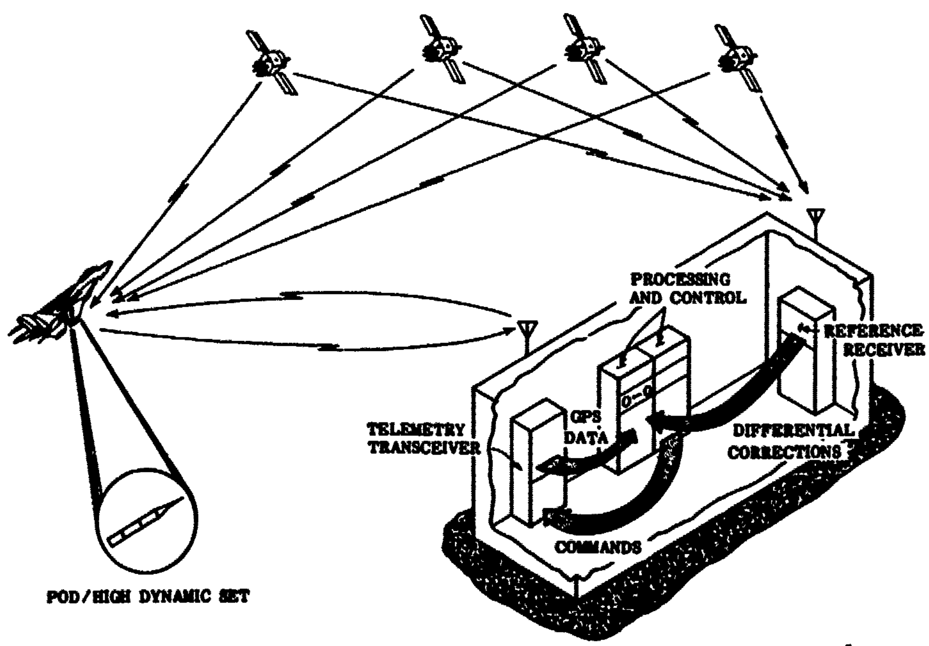

FIGURE 4 POD SYSTEM CONCEPT

Each GPS satellite transmits a navigation signal containing a precise(P) code and a clear/acquisition(C/A) code. Expected TSPI accuracies for authorized users of these codes are shown in Table 3. The P-code is significantly better for absolute position and velocity determination but in the differential mode (using a P-code reference receiver) both codes provide essentially equivalent velocity accuracies with the P-code being only slightly better for position determination(8). Since P-code is less susceptible to multipath errors and since P-code receivers are only slightly more complex and costly, P-code is recommended for receiver applications. The C/A code is selected for translator applications because significantly less bandwidth is required (2 megahertz vs 20 megahertz).

		ABSOLUTE		DIFFERENTIAL	
		P-CODE	C/A CODE	P-CODE	C/A CODE
REALTIME	POSITION (M)	14	30*	8	10
	VELOCITY (M/S)	0.2	1*	0.04	0.04
POST MISSION	POSITION (M)	7	30*	6	7
	VELOCITY (M/S)	0.1	1*	0.04	0.04

CONDITIONS: APPROXIMATE THREE DIMENSIONAL RSS ERROR, PDOP = 3
POINTWISE SOLUTIONS (1 Hz POSITION, 10 Hz VELOCITY)
NO MULTIPATH ERRORS OR UNCOMPENSATED DYNAMICS
* NO IONOSPHERIC REFRACTION CORRECTION

TABLE 3 EXPECTED GPS TSPI ACCURACY

The performance of current receivers with respect to data continuity is not satisfactory for applications on the ranges. The time-to-first-fix must be reduced from "minutes" to a few seconds, and reacquisition after signal loss (for example, when an aircraft banks and masks the GPS antenna) lowered to a fraction of a second. Three techniques have been proposed to improve data continuity. First, rapid signal acquisition methods have been defined and are being tested(9). Secondly, an inertial reference unit integrated with the GPS receiver could provide data through a masking period and assist the receiver tracking loops to quickly reacquire. Lastly, fixed ground simulated satellites, "pseudolites", at key locations could reduce or eliminate outages. However, pseudolites may present interference and signal capture problems due to the large differences in signal strength with the satellites.

IMPLEMENTATION ISSUES

The key implementation issues concern the cost-effectiveness of a GPS approach compared with existing instrumentation systems, and the future integration of GPS equipment at the ranges. The generic ranges were analyzed from a cost-benefit standpoint assuming future evolution of both non-GPS and GPS equipment suites(10). The "Mobile Sea" range was omitted because a fully developed system at sea did not exist and comparative costs could not be obtained. Figure 5 shows the twenty year life-cycle cost results for the remaining seven generic ranges, all normalized to a hypothetical present day sunk-cost baseline. In other words, the cost comparison was done from the present time forward assuming an existing suite of non-GPS instrumentation that must be maintained, operated, modernized, and improved in future years.

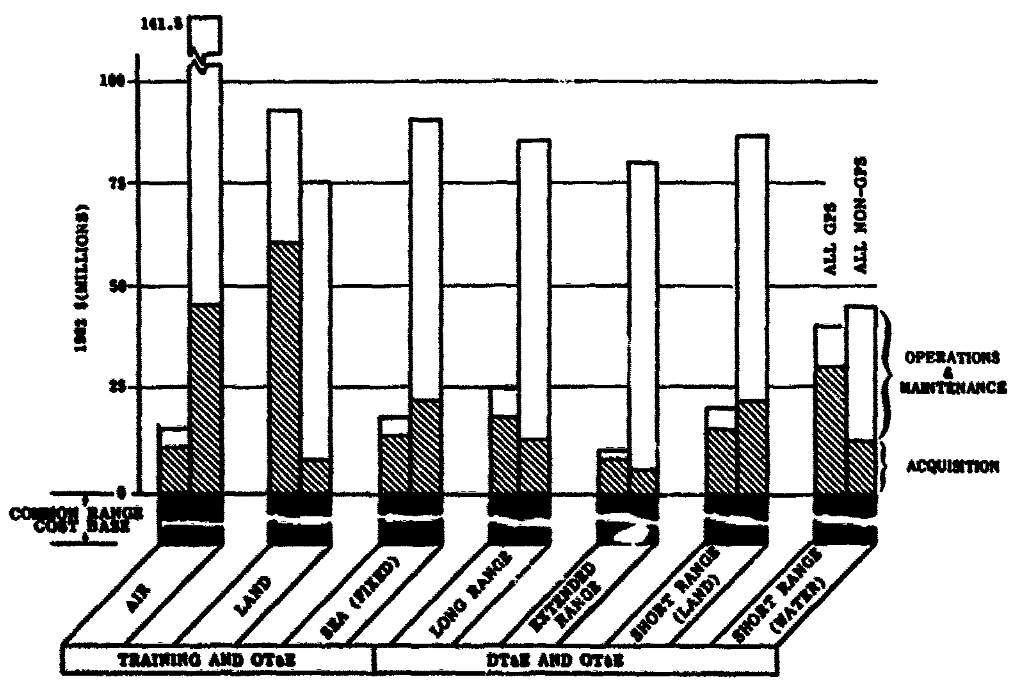

FIGURE 5 DIFFERENTIAL LIFE CYCLE COST SUMMARY

		ABSOLUTE		DIFFERENTIAL	
		P-CODE	C/A CODE	P-CODE	C/A CODE
REALTIME	POSITION (M)	14	30*	8	10
	VELOCITY (M/S)	0.2	1*	0.04	0.04
POST MISSION	POSITION (M)	7	30*	6	7
	VELOCITY (M/S)	0.1	1*	0.04	0.04

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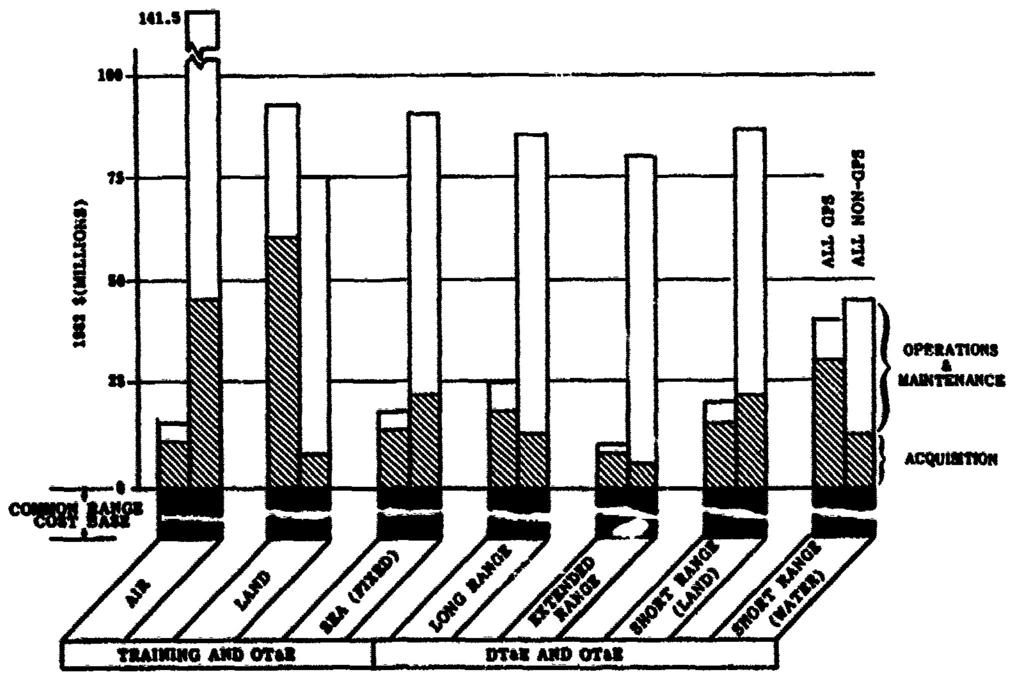

FIGURE 5 DIFFERENTIAL LIFE CYCLE COST SUMMARY

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